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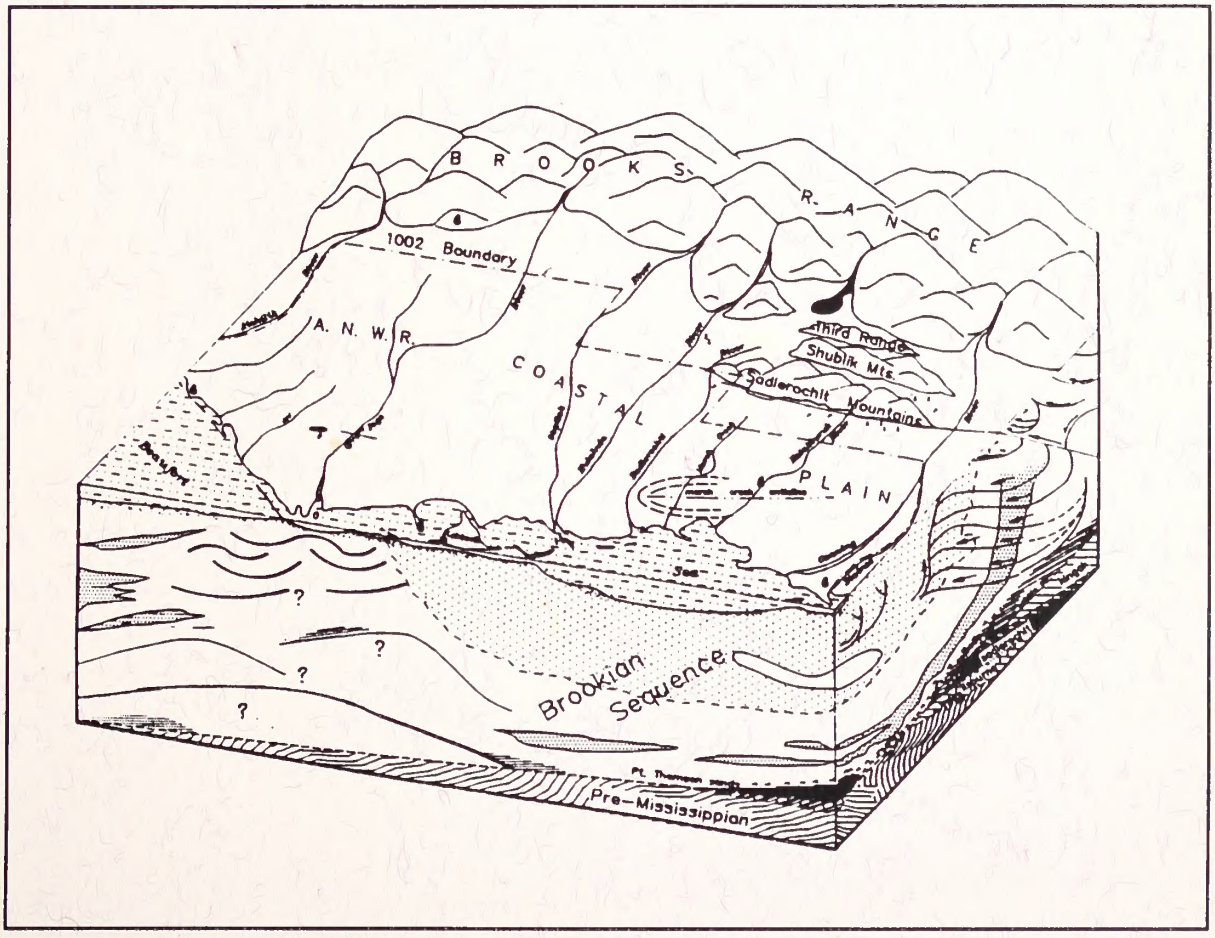
Oil and Gas Development on Alaska's North Slope: Past Results and Future Prospects

Arthur C. Banet, Jr.



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Exploration

Alaska's northern frontier is the North Slope. This physiographic province extends some 500 miles from Cape Lisburne to the Canadian border (and on to the Babbage River in the Yukon Territory).

The Brooks Range forms the backbone of this area. Topographic relief and geological complexity decrease to the north as the mountainous terrain of the continental divide gives way to foothills and the coastal plain. These foothills are a band of tundra-covered low relief hills, rounded ridges, and river valleys approximately 50 miles wide and parallel to the mountain front. Further north, the coastal plain consists of extremely flat country typically dotted with lakes and boggy lowlands. It varies in width from 25 to 120 miles. The continental shelf extends another 40 to 60 miles beneath the seasonal icepack of the Arctic Ocean *(figure 1)*.

The Alaska North Slope is the focus of most current large-scale oil and gas interests. The prospective area is some 50,000 square miles onshore. The National Petroleum Reserve-Alaska (NPRA) alone is approximately the size of Indiana.

This last frontier was not explored or mapped until the turn of the century. While Brooks and Leffingwell were reporting the existence of oil and gas seeps or oil-stained rocks in Alaska, the Middle East (Iran) began its first production. Table 1 is a concise chronology of North Slope oil and gas exploration current through 1990.

Industry and government interests in the North Slope began in earnest in the 1920s following establishment of Naval Petroleum Reserve #4 (NPR-4 which later became NPRA) by President Harding in 1923. Surface mapping showed many anticlines and more oil and gas seeps that are prospective for exploration.

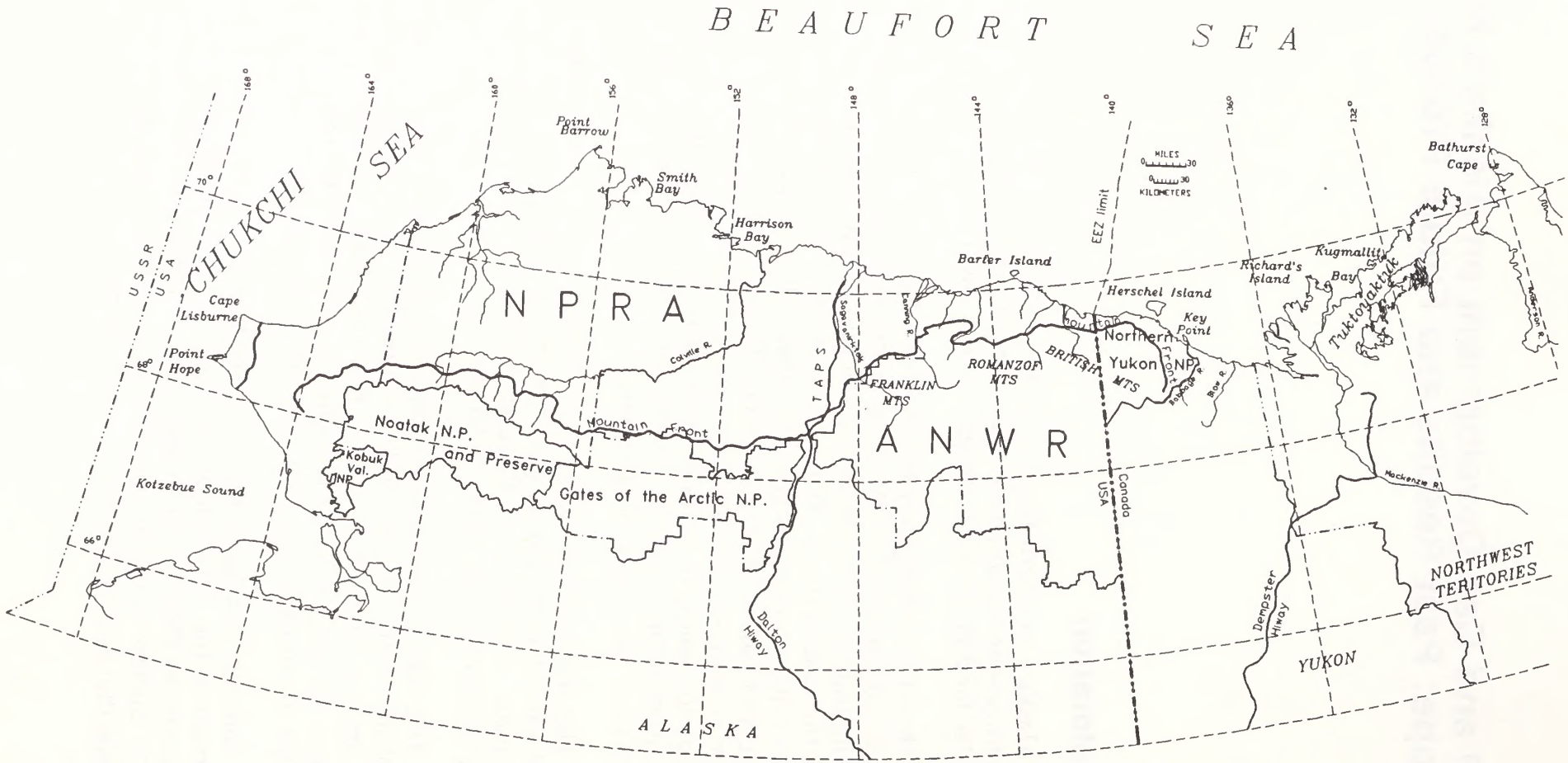

Figure 1. Index map of the Arctic showing major geographic features in Alaska, Yukon Territory and the Northwest Territories

The entire North Slope was withdrawn from mineral entry by Public Land Order (PLO) #82 because of World War II. This was the beginning of the Navy's exploration and surface mapping program.

The Navy drilling program began in 1944. By 1953, it had identified and semi-quantitatively tested three oil fields: Umiat (which actually produced some oil for local usage), Fish Creek and Simpson) and six gas fields: Barrow, Gubik, Titaluk, Wolf Creek, Square Lake, and Meade).

Most of the drilling during this initial exploration phase was shallow, typically less than ~3000 ft. Drilling tested 18 of the surface-mapped anticlines. The initial phase of exploration cost approximately $60 million *(figure 2)*.

With the discovery of the Swanson River oil field on the Kenai Peninsula, federal land became available for exploration in Alaska via simultaneous oil and gas applications (SIMO). The BLM initially opened some four million acres on the North Slope east of NPRA and offered 16,000 acres for competitive bidding *(figure 3)*.

This was the first public offering of lands since PLO #82 withdrew all North Slope lands. This and later land offerings staged in a scheduled manner greatly aided industry's decision-making process. Industry had to consider remote locales, high risk, and high-cost exploration problems in addition to state and federal regulations and legalities. Subsequent exploration plans were designed around this process.

The 1960s brought about the first seismic exploration on the North Slope since tests run in NPRA in 1953. This was a broad, wide-spaced grid looking for large structural trends with potential targets in the areas soon to be opened for exploration between the foothills and the coast, and from Colville to Canning Rivers *(figure 3)*.

In 1960 Congress created the Arctic Wildlife Range which removed some nine million acres of the eastern North Slope from exploration considerations *(figure 1)*. The oil industry exploration effort was aided by the Department of the Interior which allowed the formation of development contracts. This action effectively removed lands leased by operating companies in contract areas like the North Slope from federal chargeability limits provided they had DOI-approved exploration programs and specified minimum annual expenditures. This action gave substantial financial incentive for companies willing to invest the capital necessary for exploring in a high-risk environment. The immediate result was that industry exploration drilling began testing surface-mapped anticlines in the central arctic area and discovered subeconomic gas fields *(table 2)*.

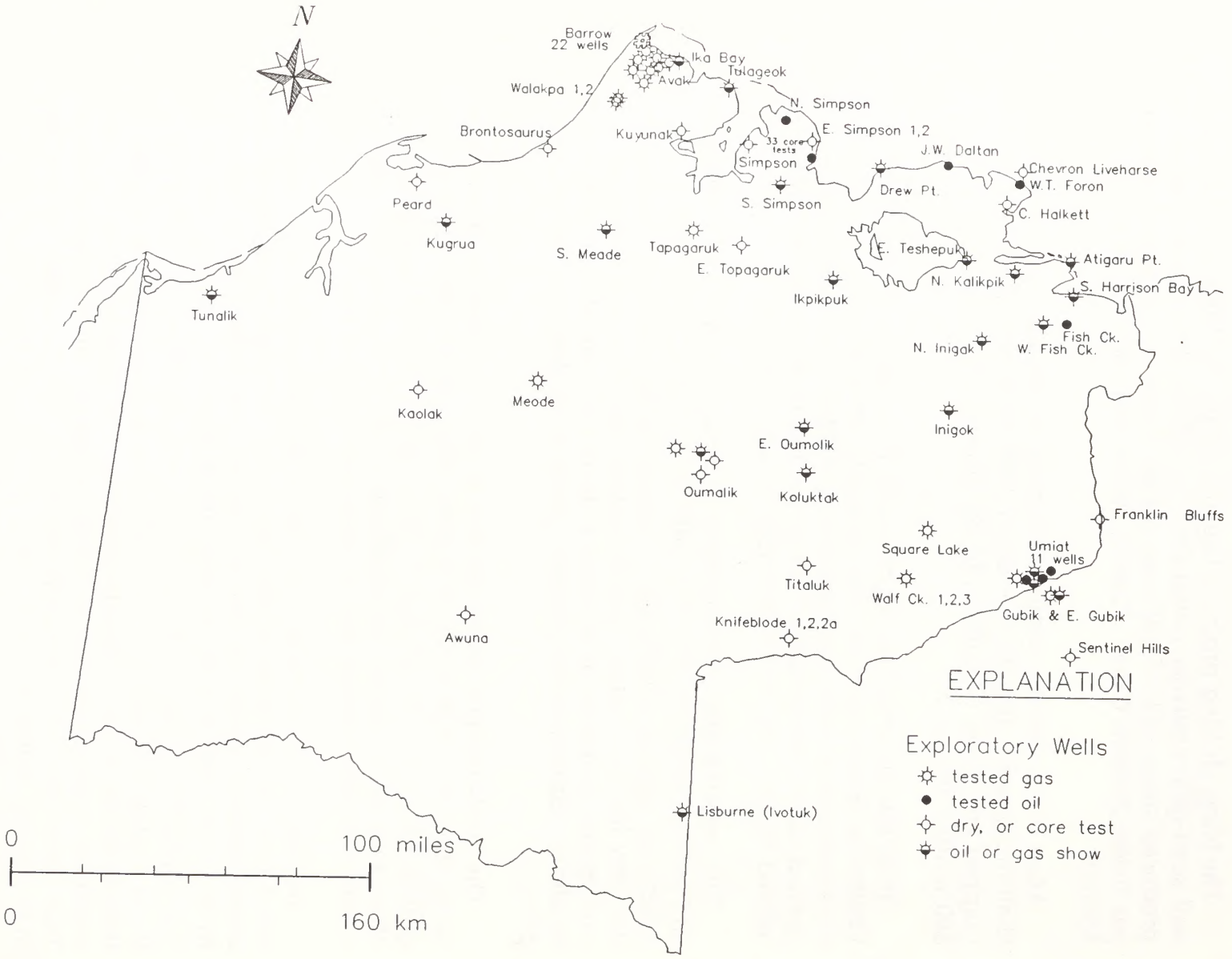

Figure 2. National Petroleum Reserve—Alaska well locations

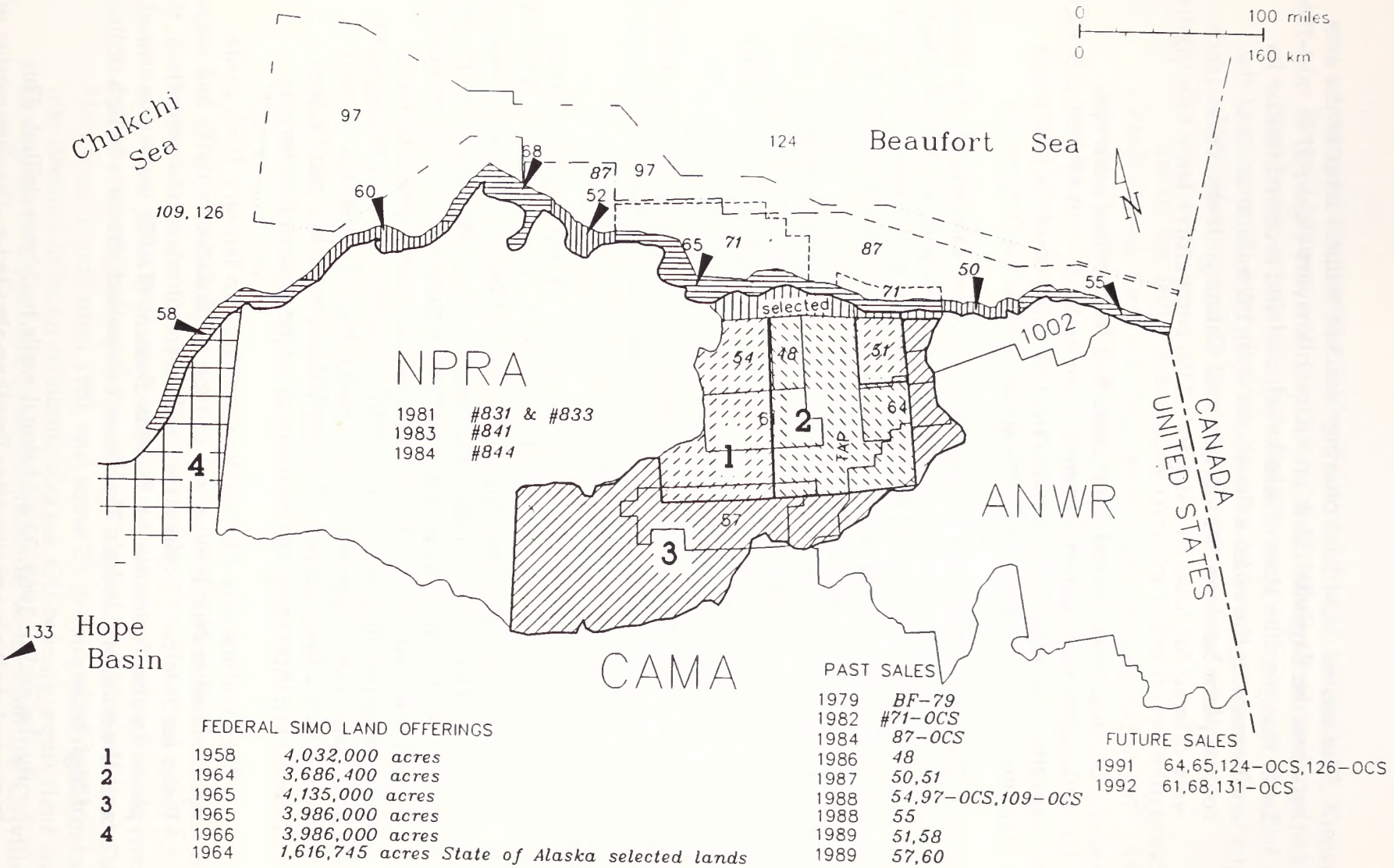

Figure 3. Federal North Slope lands opened to exploration with subsequent state of Alaska and federal Outer Continental Shelf offerings

The second BLM land offering was 3.68 million acres in the area between the Sagavanirktok and Kuparuk rivers *(figure 3)* in mid-1964. Later that year the state of Alaska selected and received (under its entitlement in the Alaska Statehood Act) 1.6 million acres of the coastal plain between the Colville and Canning rivers. These lands were offered for lease in the state's 13th competitive lease sale *(figure 3)*.

Because these coastal plain areas had few surface outcrops, exploration methods shifted to seismic methods. BLM's third SIMO offering was eight million acres including the foothills and tracts immediately west of the Canning River *(figure 3)*.

The state of Alaska's 14th competitive lease sale offered the coastal plain acreage of the Prudhoe Bay field. Richfield (now part of ARCO) and Humble (now Exxon) took 28 blocks along the crest, with British Petroleum (BP) acquiring 32 blocks along the flanks of a large, but subtly defined combination structural-truncation/subcrop seismic target. A year later in 1966 BLM offered another three million acres west of NPRA *(figure 3)*. In 1967 ARCO-Humble acquired the remaining crestal blocks in the Prudhoe Bay area in Alaska's 18th competitive sale.

In late 1966 the BLM's fourth SIMO offering received very limited interest and no leases were offered because of the likelihood for passage of the Alaska Native Claims Settlement Act (ANCSA).

By 1967 and 1968 industry exploration and drilling had slowed dramatically as indecision about draft verbiage proposed for ANCSA effectively created a moratorium on federal lands. Although there were 19 plugged and abandoned exploration holes in the central arctic area, important information was gleaned from these efforts that indicated the existence of reservoir rock beneath the coastal plain. Original exploration strategies counted on the presence of thick, widespread, Paleozoic, carbonate reservoirs. The BP-Sinclair Colville #1 well penetrated a thick section of upper Paleozoic deltaic sandstones, effectively increasing the number of major exploration targets.

The Prudhoe Bay discovery, announced in January 1968, came when all other North Slope oil and gas exploration activity had ceased. Plans for five new exploration wells were immediately submitted, the plans for the Trans-Alaska Pipeline System (TAPS) were announced, and the state of Alaska's 23rd lease sale netted almost a billion dollars of high bids.

By the end of 1969, 33 additional wells had been drilled. This increased drilling activity after Prudhoe also led to the discoveries of

many of the satellite fields of the region such as Endicott, Kuparuk River, Lisburne, and Niakuk *(table 2)*. While these are large fields by "lower 48" standards, their development still remains clouded in the controversial interplays of unstable oil pricing, international supply vs. demand, state and federal regulations, and tax schemes.

Oddly the 1970s began quite contrary to the fervor with which the 1960s closed. Only six exploration wells were drilled in 1971. ANCSA freed up some lands for exploration as Native corporate concessions and tied up other lands in ownership disputes. Environmental considerations delayed the permitting of TAPS until after the 1973 oil embargo that followed the Yom Kippur war in the Middle East.

Even with the prospects of long lines at gas pumps, Congressional approval of the TAPS right-of-way was deadlocked in the Senate until Vice-President Agnew cast the deciding vote allowing the development of North America's largest oil field. TAPS construction began in 1974 and the first oil flowed in mid 1977. By comparison, Ekofisk (discovered in the North Sea in late 1969 after the drilling of some 200 exploration wells), began producing in 1971!

Continued drilling and development at the Prudhoe field identified in-place reserves of approximately 26.9 billion barrels of oil and almost 30 trillion cubic feet (TCF) of natural gas. Initial estimates of 9.6 billion barrels of recoverable oil have been increased to more than 12 billion barrels owing to secondary and tertiary recovery schemes such as gas injection, the addition of surfactants, water flooding and horizontal drilling.

Although Prudhoe Bay is the largest single natural gas accumulation in North America, the economics still are not favorable for the construction of a high pressure gas pipeline to tap the resource. Additional drilling in the Prudhoe Bay area has identified more oil and gas accumulations *(table 2)* of varying size, stratigraphic position and resource base. In fact most of the stratigraphic units are oil-bearing in this area. They were usually drilled through and tested, but not developed, owing to the importance and size of the Prudhoe Bay reservoir *(figure 4)*.

The Kuparuk River field is immediately west and stratagraphically upsection of the Prudhoe Bay reservoirs. This field has some 4.5 billion barrels in place with an estimated recoverable reserve base of two billion barrels, making it the second largest field in the United States. However, it took until 1981 and some 25 development wells before it was deemed to be an economic success. Oil-bearing, equivalent age and stratigraphic units have been identified in wells from the Colville delta in the west to the Canning River (Point Thomson) in the east *(plate 1,*

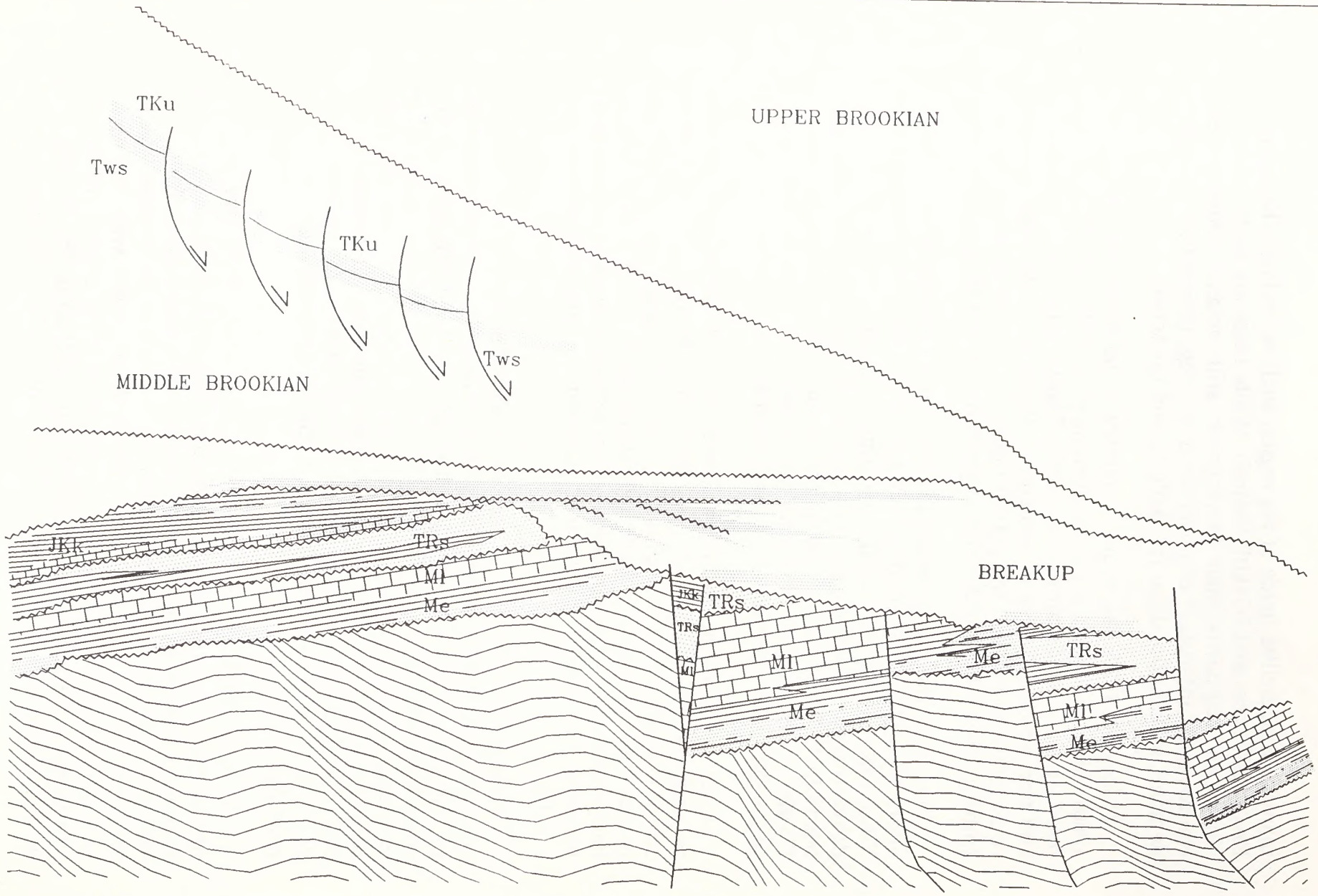

Figure 4. Diagrammatic cross section illustrating major North Slope petroleum traps: the truncation/subcrop at Prudhoe, the Breakup sequence sands of Kuparuk and Point McIntyre, the down-dropped blocks of Seal Island and Niakuk, the West Sak and Ugnu.

Note: faults and formation thicknesses are highly stylized

table 2). The Kuparuk River and Milne Point fields are the only developments on line thus far, despite the size of reserves at Point Thomson and Pt. Mcintyre *(table 2).*

The shallowest reservoirs in the area may contain the largest share of the in-place reserves. Estimates of up to some 40 billion barrels are cited for the in-place oil reserves in the West Sak and Ugnu sands. This oil saturates a large area *(plate 1).* However, it has a lower reservoir temperature and lower API gravity than the typical Prudhoe Bay accumulations. Expensive or improved technology will be needed to effect efficient recovery from these units. ARCO has an experimental development program and Conoco has requested permission from the Alaska Oil and Gas Conservation Commission (AOGCC) to initiate production from these sands at the Milne Point field.

There is commercially producible oil downsection of the Prudhoe reservoirs *(figure 4).* The Lisburne field taps reservoirs immediately beneath the main Prudhoe Bay complex and the Endicott field is immediately northeast *(plate 1, table 2).* The Endicott field is currently the most northernmost producing offshore oil field in the world. Further offshore, potentially commercial reserves, have been identified at Seal Island and Niakuk from Prudhoe Bay-type reservoirs on structurally "down-dropped blocks."

Onshore exploration drilling continues, but at a much slower pace south of the Prudhoe Bay complex.

Beaufort Sea

Offshore exploration began with the joint state of Alaska and federal BF-79 sale including "disputed ownership" tracts immediately offshore. More recent offerings include federal Beaufort Sea sales #71 in 1982, #87 in 1984 and #97 in 1988. State of Alaska sales #50 and #55 followed in 1987 and 1988, respectively.

Offshore (OCS) exploration is in its infancy with approximately 21 wells drilled to date. All but one of these wells have been drilled very close to shore in very shallow water. Five of these are considered important discoveries *(table 2)*.

The others have had shows or noneconomically producible oil and gas, based on tests of the Prudhoe truncation/subcrop play and the down-dropped blocks play. Most notable was the Mukluk well which cost approximately $100 million for the gravel island and another $40-50 million to drill. Although it was a geologic success (i.e. it encountered the expected stratigraphic section), it failed to produce the Prudhoe Bay-type of discovery offshore. However, some heavy oil was recovered.

The shallower and younger plays are only now coming into consideration as economically viable targets. Exploration strategies now include consideration of the Breakup sequence section that produces at the Kuparuk River field. In addition, successes across the border in Canada stimulate interest in the shallowest plays such as the Hammerhead prospect *(table 2)*.

Canada (Mackenzie Delta and Beaufort Sea)

Immediately following the success at Prudhoe Bay, drilling began in 1971 on the Yukon Coastal Plain and in the Mackenzie Delta *(plate 1)*. The next year saw exploration spread offshore from the delta and up north into the Arctic Island Archipelago. Table 2 lists the chronology and sizes of the major discoveries in the approximately 40,000 square mile Mackenzie Delta and offshore area.

Most of the wells have penetrated only Upper Cretaceous and younger clastic sediments. The Geological Survey of Canada lists 240 wells drilled in this area with 49 considered to be oil or gas discoveries. This includes delineation wells on large discoveries like Amauligak, Adlartok and Koponoar.

Approximately 300,000 barrels of crude oil were tested, produced and shipped from the Amauligak discovery by tanker through the Beaufort and Bering Seas and sold to Japan in 1986. Full economic development of the area probably depends upon the construction of a pipeline

system through the Yukon Territory, and on across the Arctic Coastal Plain to the Trans-Alaska Pipeline System (TAPS).

National Petroleum Reserve Alaska (NPRA)

The dramatic price hikes and spot shortages created by the 1973 oil embargo prompted the second phase of exploration in the NPR-4. Between 1974 and 1977 the Navy contracted six legitimate deep tests along the Arctic coast. These tests explored much of the stratigraphic section and the extension of the Prudhoe Bay truncation/subcrop trends along the coast. While the existence of similar geology was confirmed, there were only minor shows of oil and gas *(table 3)*. Another shallow well found the South Barrow gas field *(table 3)*.

In 1977 the NPR-4 was renamed National Petroleum Reserve-Alaska (NPRA), transferred to the Department of Interior and the U.S. Geological Survey (USGS) took over the third phase of the exploration. Twenty-one wells were drilled in NPRA between 1977 and 1981. These wells had the benefit of some 13,000 miles of seismic data and tested truncation plays along the coast, structures in the foothills, a single mountain-front prospect and seismically-identified targets. As in the second phase, there were no commercial discoveries but there were favorable oil shows and minor gas field discoveries *(table 3)*.

In all, the NPRA drilling and seismic exploration consisted of 15,600 miles of seismic data (including the 1953 data) and 40 exploration wells with total depths between 3666 ft and 20,135 ft. (average depth <8,000ft) testing targets in an area comparable in size to the state of Indiana *(figure 2)* .

Table 3 lists the numerous shallow and/or development wells around Barrow, Simpson, Umiat and Oumalik. Total depths are between 50' and 2500' at Barrow, Umiat, Oumalik, Wolf Creek, Knifeblade and Simpson. Although 126 wells have been drilled, many of them are shallow and only 30 targets have been tested.

These explorations managed to find encouraging signs of oil and gas in almost every well drilled. In addition there are several small oil and gas fields that are not of sufficient size to warrant development in today's market place. For perspective, the exploration drilling density in NPRA is approximately one well/900 sq. miles; in the continental USA this averages one well/ sq. mile; and along the U.S. Gulf Coast 2.6 wells/sq. mile. Even the Middle East has twice the drilling density of NPRA with one well/590 sq. miles.

Drilling along the coast has shown that NPRA probably does not have a Prudhoe Bay-sized truncation/subcrop giant oil field accumulation. However, the presence of oil and gas shows does not rule out smaller and more areally limited targets like the down-dropped blocks of the Niakuk or Seal Island accumulations. Also, drilling in the Colville delta immediately east of NPRA *(table 2)* recovered considerable amounts of oil from Breakup sequence rocks.

These rocks are similar in lithology and age to the Kuparuk River field reservoirs and they have been identified on logs from wells across northern NPRA. The potential of both these plays, the down-dropped blocks and Breakup sequence sands is probably analogous to Niakuk or Kuparuk River with accumulations that range in size from 50 million to more than two billion barrels of oil respectively. These plays were never considered to have been primary targets during the three government NPRA exploration phases and they still have not been fully explored in this part of NPRA. They were also ignored around the Prudhoe Bay area for several years *(table 2)*.

Figure 2 shows the southern three-fourths of NPRA has been very lightly explored with only five deep tests in the entire area. In addition, the entire foothills belt has been tested only by shallow wells or wells that probably were not optimally sighted.

Figure 5 illustrates changing interpretations of anticlinal type traps related to foreland fold and thrust settings. The earlier interpretation is much simpler and has fewer potential pay zones than the more modern interpretations derived from experiences gained from considerable modern drilling of thrust fault cored anticlines along the Rocky Mountain Cordillera.

The NPRA wells and most of the central arctic wells tested these surface anticlines under older interpretations. Thus they may have not been drilled deeply enough or were perhaps poorly located for optimum testing of reservoirs. Nonetheless, small (by North Slope standards) oil and gas accumulations have been found this way. But the potential of a major play still remains unknown. Surely more analysis should be made of the Umiat field as it is part a long trend which is parallel to the entire mountain front. Umiat has estimated recoverable reserves of approximately 70 million barrels. However, drilling has tested only five similar targets in the foothills.

Only the Lisburne well has tested plays in the mountain front, where thrust faulting in the deeper and older part of the stratigraphic section is very common *(figure 5)*. This well had ubiquitous oil staining and penetrated a complex thrust faulted section of repeated limestones. Although the source of these hydrocarbons is unknown,

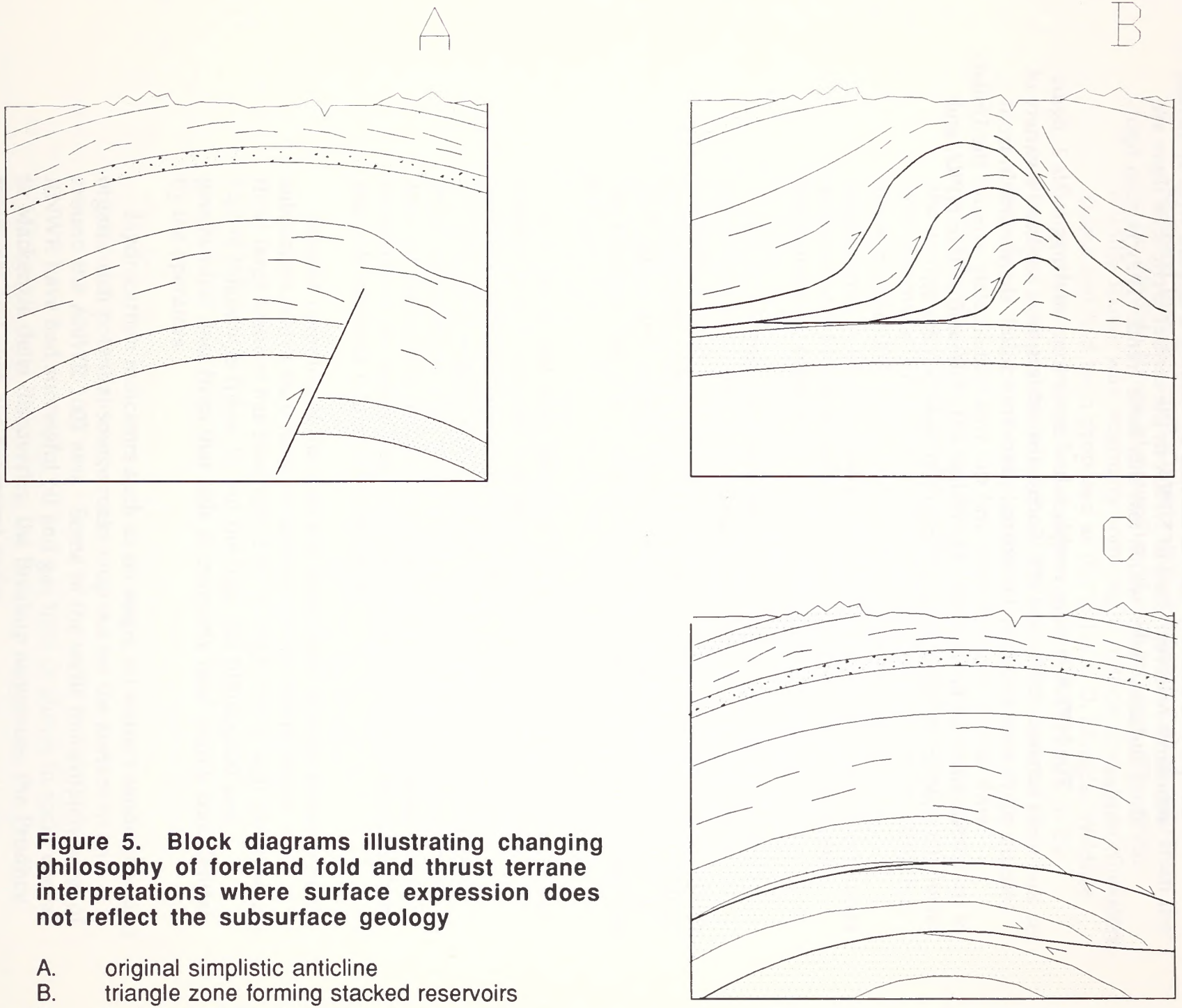

Figure 5. Block diagrams illustrating changing philosophy of foreland fold and thrust terrane interpretations where surface expression does not reflect the subsurface geology

A. original simplistic anticline
B. triangle zone forming stacked reservoirs
C. fault bend folds stacking reservoirs

these findings indicate that oil and gas have been generated, have successfully migrated through, and are still preserved in the rocks in this play. Discovery then is limited by finding a closure with sufficient economic reserves. East of NPRA in the central arctic area there are three industry holes which test this same trend. They remain tight holes.

The NPRA leasing program has made four offerings *(table 1, figure 3)* between 1981 and 1983. Successful bidders have acquired a variety of plays on tracts near the coastal plain truncation, the mountain front with several large closures and the area immediately around the Umiat oil field. So far industry has drilled only one well within NPRA and another on lands selected from the reserve *(table 3)*.

Arctic National Wildlife Refuge (ANWR)

The Arctic National Wildlife Refuge was created by the Alaska National Interest Lands Conservation Act (ANILCA) in 1980 from the Arctic Wildlife Range plus another 11 million acres. (The Arctic Wildlife Range was originally some eight million acres in northeastern Alaska and had been proposed as the William O. Douglas Wildlife Range. It is sometimes found abbreviated as WODAWR in the literature.) Approximately 1.5 million acres of the coastal plain was set aside by ANILCA (under section 1002) for further oil and gas studies.

During the 1960s, 70s and 80s, oil industry drilling progressed up to the western border of ANWR *(plate 1)*. Oil, gas and condensate have been discovered and successfully tested at the Pt. Thomson field, but the estimated 350 million barrels of recoverable reserves are uneconomic at this time *(plate 1, table 2)*. Table 2 also lists discoveries at Kavik and Kemik anticlines, immediately west of ANWR and Hammerhead, offshore.

The "1002 area" has been intensively studied for oil and gas assessment since 1983. Two seasons of seismic data and several summers of field geology show that there is a variety of oil or gas plays and prospects *(plate 2, figure 6)*. There is a truncation/subcrop similar to Prudhoe and northern NPRA in western ANWR. Outcrops of all the Prudhoe Bay area reservoir units are exposed just south of the 1002 area.

Geological and field mapping of the Marsh Creek anticline, in the western part of the 1002 area, shows that it is probably the largest undrilled surface-mapped anticline in the U.S. Seismic data interpretation suggest that this anticline is an expression of triangle zone deformation. The rocks involved are of Tertiary (i.e. younger) age, but the style of deformation is similar to that responsible for the formation of the Umiat field in NPRA and oil fields in the Canadian and U.S. foreland fold and thrust areas.

Seismic mapping of the data has delineated 26 large closures in the subsurface which may have no analogs on the North Slope. One of these large features has been tested by an exploratory well on corporate Native inholdings (plate 1), but the logs, the lithological and geochemical data from that hole is currently held highly confidential by the operators.

Hydrocarbon indicators such as oil seeps, oil stained sandstones and organic-rich potential source rocks crop out on the surface in and around the ANWR 1002 area. Some of the wells immediately west of ANWR have had successful oil and gas tests or shows in rocks coeval to Mackenzie delta discoveries, the Breakup sequences, the Prudhoe reservoirs and even the basement rocks.

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But the timing of oil formation, the geometry of hydrocarbon migration paths, and the existence of thick and areally extensive reservoir rock in the 1002 area subsurface are still unknown parts of the oil accumulation equation. Thus the conditional economically recoverable reserves are currently estimated (as of 1987) to have a mean value of 3.2 billion barrels at a marginal probability of 19 percent (A). The range of reserves is from approximately 0.6 billion barrels at the 95 percent probability to 9.24 billion barrels at the 5 percent probability of success. Based on these estimations,the Department of the Interior recommends opening the 1002 area to oil and gas leasing.

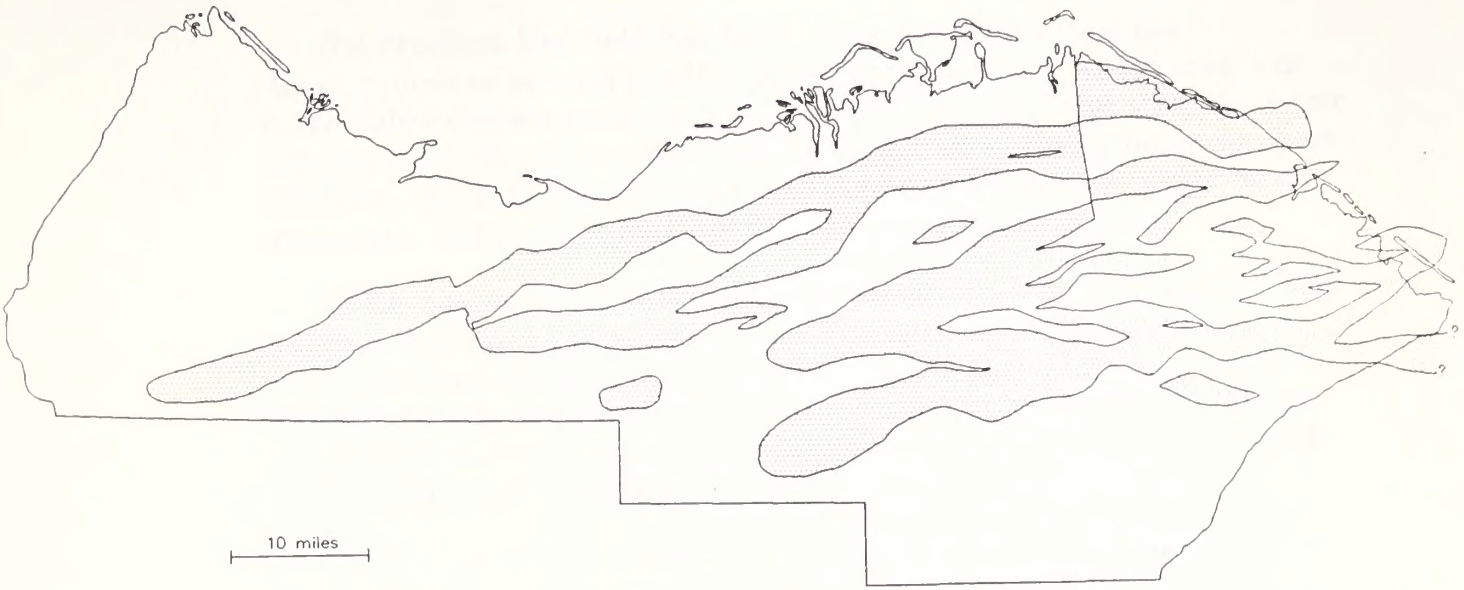
(A) Petroleum resources evaluations, assessments and volumetric estimations are not static processes. Geologic mapping, seismic information and well data continues to be gathered and incorporated with evolving economic models. There is a complex interplay of geologic parameters, development costs and economic projections of net present values that are computer-modeled behind each evaluation.

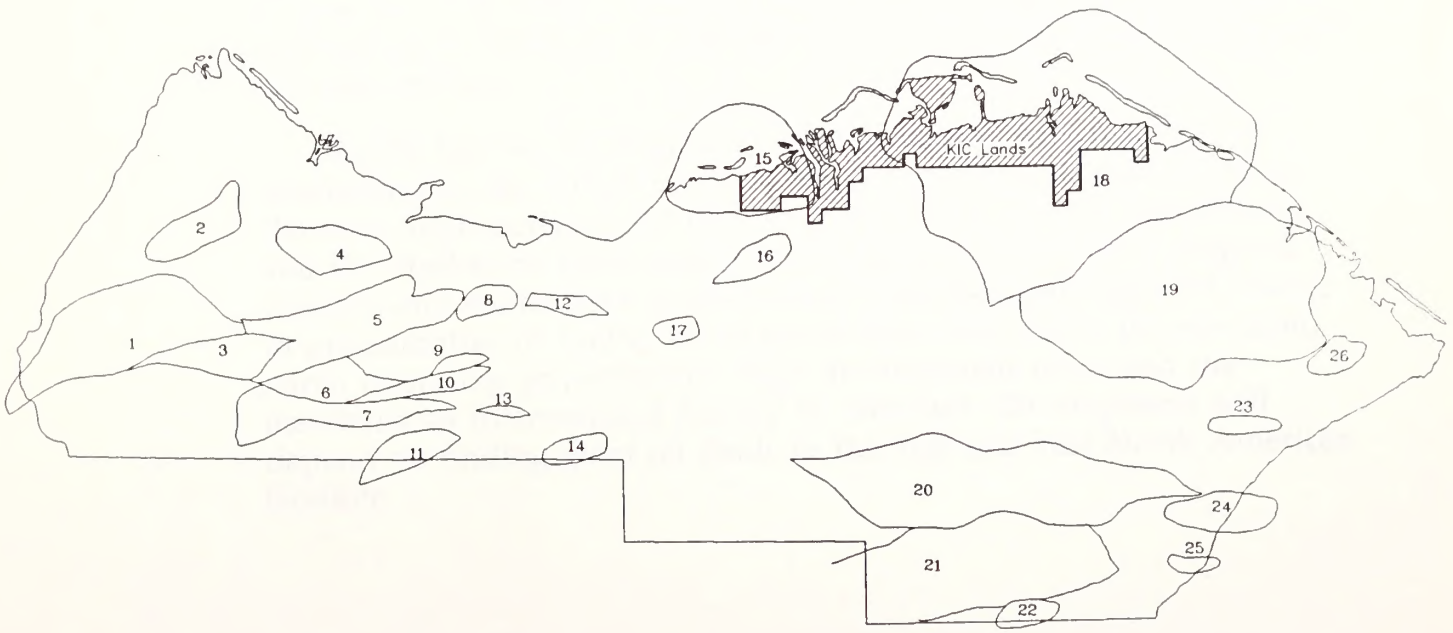
The Department of the Interior routinely publishes these assessments and estimations as data become available. It is notable that new wells have been drilled, additional seismic data has been gathered or processed, and geologic mapping has continued around ANWR since the 1987 assessment. Also, economic projections have fluctuated considerably since 1987. Consequently, updated material can become available to the Department of the Interior and should be expected as statutes pertinent to the release of confidential and proprietary information change.

Figure 6. Possible petroleum prospects in ANWR

A. Detached Jurrassic, Cretaceous and Tertiary highs

B. 26 prospects mapped at regional TPM reflector





SUMMARY

Almost fifty years elapsed between the discovery of oil and gas in the Arctic and the beginning of subsurface exploration on the North Slope. It took another twenty years of exploration steered by government financial incentives and scheduled land availability before a major world class oil field was discovered.

The Prudhoe Bay field has been large enough to spur the development of several satellite fields in the Central Arctic area, but more fields remain undeveloped owing to region's vast size, the harsh climate, unstable oil markets and the high cost of doing business there. Offshore, the U.S. Beaufort and the Canadian Mackenzie Delta have important, but smaller and not yet economic discoveries.

NPRA has not been thoroughly explored. Drilling and seismic data indicate that there probably is not a Prudhoe Bay-size accumulation along the truncation/subcrop trend along the coast. However, down-dropped blocks and Breakup sequence sands probably exist in NPRA which have not been thoroughly or systematically explored but have known potential elsewhere.

The southern part of NPRA is also lightly explored and virtually untouched by drilling designed to reach the current type of targets thought to exist in the foothills and mountain front areas. Thus, even though a Prudhoe Bay-size and type of field probably does not exist along the coast, there are some 36,000 square miles that have not been adequately tested for any kind of a hydrocarbon play. This is contradictory to the numerous indicators that suggest conditions and environments favorable to the generation, migration and preservation of hydrocarbons.

ANWR has many oil-generation, migration and preservation similarities to the NPRA but in a much smaller area. ANWR shares the same high potential for oil and gas with the NPRA, the offshore and the Mackenzie Delta locales (based on the stratigraphy, mapped closures and source rock geochemistry) and the same high risk owing to uncertainties in timing of oil generation, migration, preservation, harsh operating environment, high development costs and the instability of international supply vs. demand. Development will depend on finding giant oil fields in this last and vast North American frontier.

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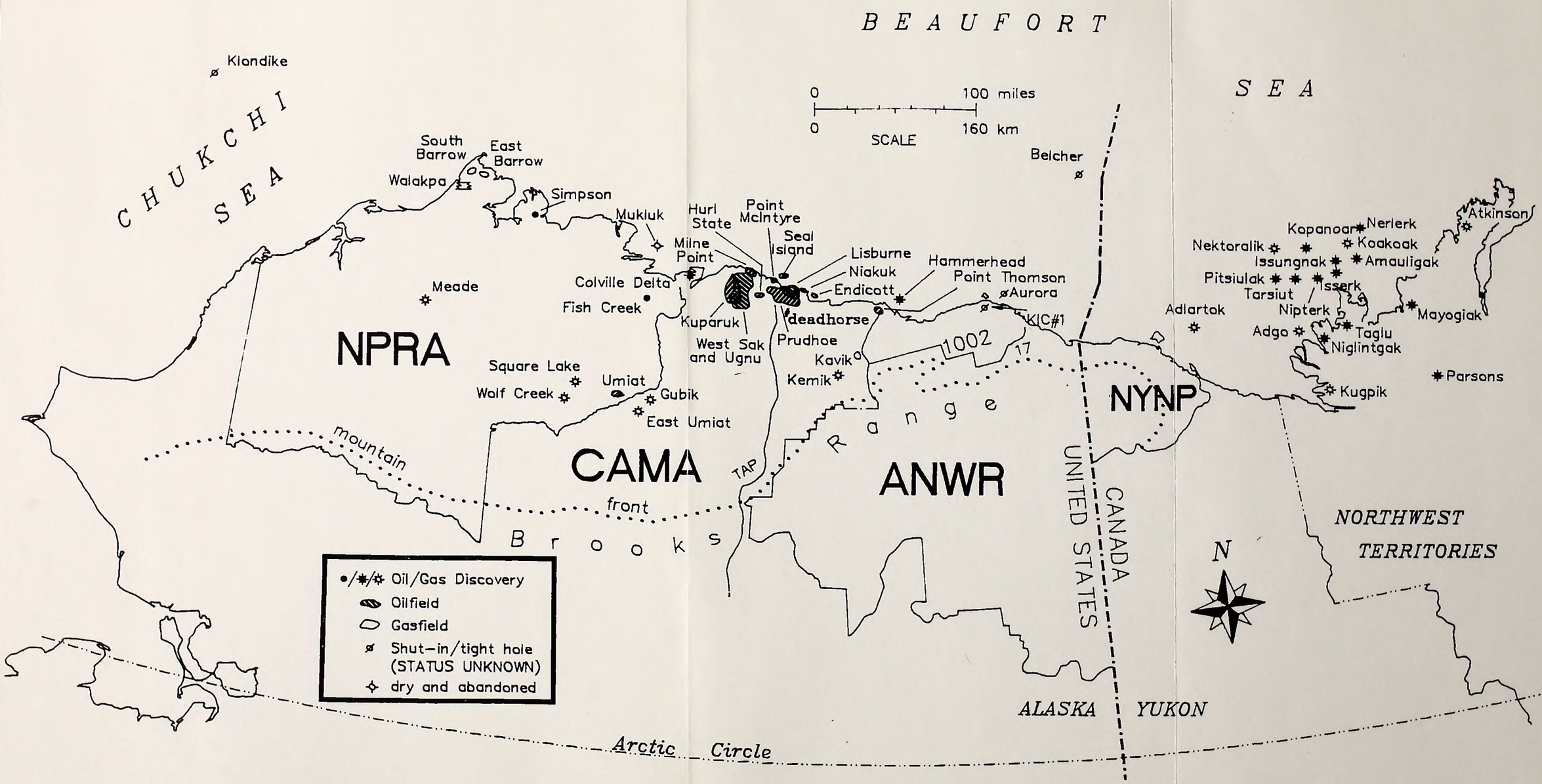
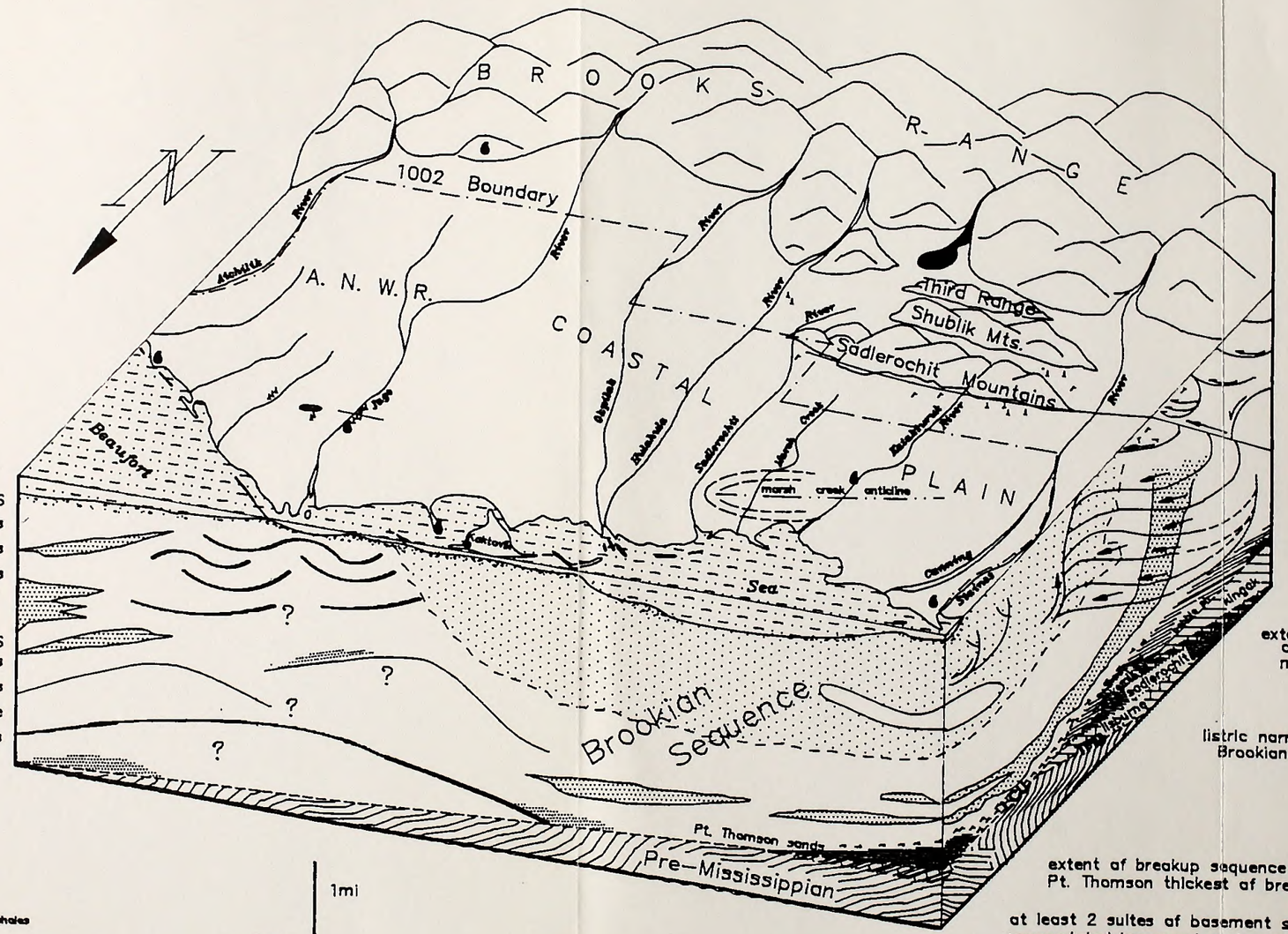


Plate 1. Some of the major oil and gas activities on the North Slope
including the National Petroleum Reserve—Alaska (NPRA), the Central Arctic Management Area (CAMA), Arctic National Wildlife Refuge (ANWR), and Northern Yukon National Park (NYNP)



COASTAL PLAIN EXPOSURES
mostly non prominent reflectors
limited lateral extents
intense multiphasic deformations

LARGE SEISMICALLY MAPPED STRUCTURES
prominently spaced multicyclic events
with intervening nonreflective zones
having apparent structural accordance
lateral continuity > 5 miles

bentonitic, high organic content, papery/cardboard shales

oil seep/oil stained sandstone

decoupling within Ellesmerian Units shown by internal folds & faults in sands and limestones

duplexing redeforms Ellesmerian and older rocks overrides and overturns Brookian units

Uplift of Katakturuk > 12,000 ft.

Marsh Creek anticline cored by short wavelength (<1mi) duplexing discontinuous seismic reflectors exposes Miocene sediments

extent of truncation at LCU unknown
constraints largely undetermined
may/not remove Ellesmerian Sequences

listric normal faults common to entire Brookian clastic wedge

extent of breakup sequence sands unknown
Pt. Thomson thickest of breakup sands

at least 2 suites of basement seismic reflectors
uncorrelated basement carbonates and argillites

Plate 2. Block diagram showing major subsurface features, faulting styles and stratigraphic relationships extrapolated into ANWR

TABLE 1:

NORTH SLOPE OIL AND GAS EXPLORATION CHRONOLOGY

1902-33	Alaska's first oil field at Katalla, ~154,000 bbls production until 1933 fire
1909	Brooks reports on oil seeps at Cape Simpson
1919	Leffingwell reports on seeps and oil stained sandstones between Canning R. and Canadian border
1920	oil discovered at Norman Wells YT
1921	prospecting permits issued for oil and gas exploration on North Slope (filed under 1872 Mining Law)
1921	Industry geologists map North Slope
1923	Pres. Harding creates NPR-4
1923-26	USGS reconnaisance mapping in NPR-4
1930	USGS results published
1943	entire North Slope withdrawn PLO #82
1943	Bureau of Mines analyzes oil seeps at: Umiat W. Dease Fish Ck. Manning Pt. Angun Pt.
1944-53	NPR-4 exploration under Navy Dept. oil and gas seeps discovered at: Skull Cliffs Meade (gas) Aukpuk Ck. Pharon Ck.
1945	Simpson Core tests 31 shallow holes (most recovered oil)
1948	1 deep oil test
1946	Umiat drilling; 3 ruined tests
1948	discovery of Barrow High (arch)
1949	Fish Creek oil discovery
1951	Umiat oil discovery
1951-52	10 NPR-4 wells on 6 structures 1500'-6000' total depths gas at Gubik Wolf Ck. Square Lake Gubik No. 2 burns w/o tests gas shows at Meade Kaolak
1953	NPR-4 exploration ends (~$60MM costs)
1957	Discovery of Swanson River oil field on Kenai peninsula south of Anchorage first giant oil field in Alaska

1958 BLM opened up ~4 million acres of North Slope
16,000 acres via comptetitive bids
remainder SIMO filing (simultaneous O&G)

1959 ALASKA STATEHOOD

1960 Arctic Wildlife Range created: (proposed as
William O. Douglas Arctic Wildlife Range)
~9 million acres on Arctic coastal plain

1961 Sinclair and British Petroleum form joint
exploration agreement for North Slope

1962-64 Industry exploration includes seismic and
geology in Central Arctic area
Dept. of Interior allows Development Contracts
for remote locales-- substanstial cost
incentives for remote exploration
BP drills 7 wells
drilled on surface anticlines
found Cretaceous sands
subeconomic gas reserves

1964 (mid) BLM SIMO filing on 3.68 million acres
in Central Arctic

1964 Richfield and Humble form joint exploration
first CDP seismic to coast

1964 State selects 80 townships on Arctic Coast
from Colville R. to Canning R.
approximately 1.6 million acres

1964 first State of Alaska competitive lease sale
on North Slope 625000 acres leased

1965 change from surface geology to seismic explo-
ration as main emphasis
BLM SIMO filings on 8 million acres
(July) first Prudhoe area lease
(14th overall State lease)
Colville No. 1 and Kookpuk No.1 wells
discovered subsurface Sadlerochit sands
HELD CONFIDENTIAL BY UNION & BP

1966 open lands west of NPRA
3 million acres SIMO: no leases due to
uncertainties in ANSCA drafts
and following land moratorium
(ANCSA Alaska Native Claims Settlement Act)

1967 halt all seismic geology and drilling
due to ANCSA implemtation uncertainties

1968 January: Humble and Richfield (ARCO)
ANNOUNCE PRUDHOE BAY DISCOVERY!!
19th well of Central Arctic exploration

1969	STATE OF ALASKA BILLION DOLLAR LEASE SALE!!
	$1.68 billion bid
	$0.9 billion high bids
	413,000 acres offered
1969	Exxon Manhattan completes northwest passage
	with load of Prudhoe Bay oil
1969	TAPS announced projected cost $8 million
1969	33 more wells
	KUPARUK RIVER FIELD DISCOVERY
1969	Ekofisk discovery in North Sea
1970	Determine reserves at Prudhoe
	~9 billion barrels
1970	oil discovery at Gwydyr Bay/Pt Mcintyre
1971	6 exploration wells
	29 development wells
1971	West Sak/Ugnu discovery
1971-73	Drilling on Yukon Coastal Plain
	IOE Spring R. & Roland Bay
1972	Navy starts re-exploration of NPR-4
1972	begin offshore Mackenzie Delta exploration
	from gravel islands
	gas discovery at Parson's Lake
1972	first oil discovery in Canadian Arctic Islands
1973	Middle East conflict
	oil embargo
1974	begin construction on Haul Road
1974	first offshore oil discovery at Adgo
1974-77	subsurface exploration in NPR-4
1975\	
1976	7 wells drilled in U.S. Navy program
1977/	
1977	Point Thomson discovery west of ANWR
1976	ice stregthened drill ships in Beaufort Sea
1976	oil at Niakuk
1977	complete pipeline consruction (TAPS)
1977	oil begins to flow
1977	NPR-4 renamed NPRA transferred to DOI
1977-81	USGS-NPRA exploration
	~$625 million exploration effort
1978	south part of North Slope closed to
	oil, gas, and mineral exploration
	(Federal Lands Policy Management Act-
	FLPMA affects ~110 million acres)
1979	Joint State/Fed sale #BF-79 offshore

1980	ANILCA Arctic National Wildlife Refuge created AWR/WODAWR + 11 million acres sets aside 1.5 million acres of the coastal plain for oil and gas exploration and possible development
1980	16 Canadian wells: 4 oil, 5 gas
1981	Begin production at Kuparuk 25 delineation wells drilled prior to decision to produce
1981	13 Canadian wells: 5 oil/gas
1981	Resource Assessment, Evaluation and Field Operations reorganized from USGS Conservation Division to Minerals Management Service (MMS)
1982	NPRA sale #831 NPRA sale #833
1982	Beaufort OCS sale #71 Beaufort Sea DGGS Sale #59 immediately west of ANWR
1982	12 exploration wells: 3 oil discoveries in Mac delta, gas in Arctic Islands
1983	Endicott Field comes onstream northenmost offshore production
1983	NPRA lease sale #841
1983	Lisburne Field comes onstream
1983	11 Canadian exploration wells: not economic
1983	All Onshore Resource Evaluation, Assessment and Field Operations reorganized from MMS to Bureau of Land Management (BLM) Division of Minerals
1983-86	Government and Industry exploration in ANWR
1983-84	first year of seismic exploration in ANWR
1983	SOHIO OCS Y-0334 Mukluk well drilled & tested possible northwest extension of the Prudhoe trend. Cost ~140 million. tested minor oil from Lisburne
1984-85	second year of seismic in ANWR
1984	Beaufort OCS sale # 79
1984	Seal Island discovery
1984	Milne Point comes onstream
1984	Amauligak Discovery, Mackenzie delta 27 exploration wells: 4 oil, 3 gas Tuk largest onshore wet gas discovery

1984-85	Chevron KIC #1 well at ANWR tight hole
1985	Horizontal drilling begins at Prudhoe increased produciton at J23, B30, Y20
1985	34 Canadian exploration wells Nipterk, Adlartok discoveries
1985	Unocal Hammerhead discovery Beaufort Sea
1986	Amoco Mars OCS Y0-0302 drilled from ice island ~$22 million costs
1987	ANWR Coastal Plain Assessment Report identifies 26 large structures estimates 3.2 billion barrels oil "conditional economically recoverable"
1987	DGGS sale #50 Camden Bay north of ANWR
1987	DGGS sale # 54 Kuparuk Uplands
1987-88	Tenneco Aurora #1 well immediately north of ANWR: remains a "tight hole"
1988	OCS sale #109 Chukchi Sea
1988	OCS sale #97 Beaufort Sea
1988	39 exploration wells: 3 oil, 3 gas Mac delta
1988	creation on Northern Yukon National Park on northwest Yukon coastal plain
1988	Shell Corona well in Camden Bay
1988-89	Amoco Belcher well Eastern Beaufort
1989	DGGS sale #55 Demarcation basin
1989	Prudhoe Field begins inexorable decline
1989	Grounding and spill of the Exxon Valdez
1989	ARCO's Kuparuk Field spill
1989	Alaska legislature changes ELF (economic limit factor) oil taxation
1989	Shell Klondike well in Chukchi Sea
1990	ARCO asks permission to tap shallower sands at Lisburne field
1990	Environmentalists request sale #55 leases be negated
1990	ARCO requests drilling depth extension on Stinson well, immediately northwest of ANWR
1990	BP announces plans to develop Hurl State prospect
1990	Conoco asks permission to produce shallower Cretaceous sands at Milne Pt.
1990	Iraq invades Kuwait North Slope crude soars to >$30.00/bbl.

FIELD	YEAR	SEQUENCE	FORMATION	RESOURCES	DST RESULTS	RES. DEPTH	TRAP	comments
Barrow	49	L Break Up	Simpson ss	713 MM m^3	~200 M m^3	500 – 700	structural ?	
E.Barrow	74–87	L Break Up	Simpson ss	>500 MM m^3	(~20 Fed wells)			some produceable oil 2 more gas wells in '87
Colville Delta	85	U Break Up	Ugnuravik	undetermined	~150 MT		strat	
Endicott	78	L Ellesmerian	Kekiktuk Cgl.	52 MM MT 20 MMM m^3	650	2900 – 3000	strat/struc/fault	offshore production, 11 wells 2 zones, 75m net pay
Fish Ck.	49	L Brookian	Nanushuk	undetermined	~30 MT	2500	strat	
Gubik	51	L Brookian	Nanushuk	4.2 – 8.3 MMM m^3	225 M m^3	2000	anticline	20 – 30 m net pay some produceable oil
Gwydyr Bay/ Pt. McIntyre	69	U Break Up U Ellesmerian	Ugnuravik Sadlerochit	42 MM MT 3.5 – 10 MM MT	50 MT 100 – 400 MT	2500 3300	fault block	30m net pay
Hammerhead	85	U Brookian	unnamed		~300 MT	1650 – 1675	anticline/fault	2 wells, 2 zones + gas
Kavik	69–74	L Break Up	Kemik	28.3 MMM m^3		1300	anticline	3 wells +oil show
Kemik	72	U Ellesmerian	Shublik	28.3 MMM m		2500	anticline	produces from fractures
Kuparuk	69–83	U Break Up	Ugnuravik	210 MM MT 18 MMM m^3	180 – 700 MT	1775 – 1900	strat/hydradynamic	1 – 15m net pay 2 productive sands 630 MMM MT in-place
Lisburne	68–83	M Ellesmerian	Lisburne	23 – 30 MM MT				
Meade	50	L Brookian	Nanushuk	280 – 270 MM m^3	30 M m3	300 – 1000	anticline	1 well, 8 DST's deeper blow
Milne Pt.	69–84	U Break Up	Ugnuravik	14 – 17 MM MT			fault block	
Niakuk	76	U Ellesmerian	Sadlerochit	9 MM MT			fault block	
North Prudhoe	69–89	U Ellesmerian	Sag R. Sadlerochit	10 MM MT			fault block	
Prudhoe Bay	68–79	U Ellesmerian M Ellesmerian	Sag R. Shublik Sadlerochit Lisburne	1540 MM MT 765 MMM m^3	2240 MT (500 – 700 MT avr.)	2650 – 2750	strat	LARGEST FIELD IN NORTH AMERICA ~4.144 MMM MT in-place 850 MMM m^3 in place
Pt. Thomson	70–83	M Brookian L Break Up Neruokpuk? N5?	Turbidites Thomson ss	49 MM MT 141 MMM m^3	350 MT 63 MM m^3 320 MT 368 M m^3 25 MT 70 M m^3	3529–3850 3950–4232	strat	15 wells in Unit ~100m max net pay
Seal Island	84	U Ellesmerian	Sadlerochit	42 MM MT			fault block	
Simpson	80	L Brookian	Nanushuk	0.3 – 1.7 MM MT	20 MT	surface – 2000	strat/ fault	includes 32 shallow core tests only 2 deep wells >2000m
Square Lake	52	L Brookian	Nanushuk	1.2MMM m^3	3 M m^3	475	anticline	2 wells
Umiat E. Umiat	46–63	L Brookian L Brookian	Nanushuk Nanushuk	10 – 14 MM MT na estimate	100 MT 170 M m	275 – 350	anticline anticline	11 wells
W. Sak/ Ugnu	69–89	M Brookian	W. Sak ss Ugnu ss	undetermined		600 – 1400	strat	13 wells, lateral extent unknown low reservoir temperature oil (~5600 MM MT in-place)
Walakpa	80–82	L Break Up	Walakpa	na estimate	65 M m^3	800	strat	2 wells, 10 m net pay lateral extent unknown, oil shows
Wolf Ck.	51	L Brookian	Nanushuk	na estimate	31 M m^3	~1000	anticline	3 wells, all shallow
Adga	74	M Brookian	U Reindeer		154 MT		fault anticlie	first offshore discovery, multiple stacked sands
Adlartok	83	M Brookian	Reindeer/Aklak	2.8 MM MT	600 MT 53 M m^3	2647TD	fault anticline	30°API, 127m pay delta front sands
Amauligak	84–88	U Brookian	Kugmallit/ (Pullen)	110 – 130 MM MT + gas	1945 MT 955 M m^3	4002TD	fault	29°API, 1 zone, 3-way & syndep. faults
Atkinson	79	L Brookian	Kugmallit		150 MT 7.3 M m^3	2480TD		22°API, 37m pay, first Mac Delta discovery
Hansen	87	U Brookian	Kugmallit		5.8 MM m 235 MT cond.			12 intervals, 8 tests 2375 – 3165m
Isserk	78	U Brookian			280 M m			
Issungnak	80	U Brookian	Kugmallit MacKenzie	14 MM MT 70 MMM m^3	470 MT 376 M m^3	3858TD	fault	35°–38° API, 75m pay, porous, poorly cemented
Kaakaak	81	U Brookian	Kugmallit		400 MT 481 M m^3	4361TD	strat	turbidites, 210m gross/21m net pay, high P&p
Kopanoar	79	U Brookian	Kugmallit	21 – 50 MM MT	850 MT		diapir anticline	Kaponaar turbidite sand channels, overpressured
Kugpik		L Break Up	Parsons	5 – 7 MM MT				
Mayogiak		Franklinian U Brookian	Devonian Carbonate				strat/anticline	fractured carbonates in reservoir coeval to Narman Wells
Miniuk	87	M & U Brookian	Kugmallit & Reindeer		1.6 MM m^3 25 MT			2 gas zones in Kugmallit, gas & cond. in Reindeer
Nektoralik	77	U Brookian	Mackenzie Bay	18.5 MMM m^3	154 MT 253 M m^3		strat	turbidites
Nerklerk	79	U Brookian	Kugmallit		115 MT		strat	turbidites, very large seismic structure
Niglingtak	73	M Brookian	U Reindeer	3.2 MM MT	230 MT 450 M m^3		fault anticline	multiple stacked deltaic sands
Nipterk	85	U Brookian	Kugmallit		1750 MT 94 M m^3	3520TD		2 zones, 510 grass pay, 11m deep
Parsons		U Break Up	Parsons	62 MMM m^3 3.2 MM MT cond.		2682	fault anticline	Kamik, Martin Ck sands 100m net pay, 15% por., dual anticlines
Pitsiulak	83	U Brookian	Kugmallit		320 MT			31° API, pro delta sands, 36m net pay
Taglu	71	M Brookian	Reindeer	68 MMM m^3 6.3 MM MT condensate	821 M m^3	2480		delta front/ lower delta plain sands, 140m pay
Tarsiut	79	U Brookian	Kugmallit	21 – 50 MM MT	500 MT	4531TD		29°API, 48m pay, 32% por. 500–700md, pro delta
Tuk	84	U Breakup	Kamik		380 MT condensate	3030TD		51°API, 37m pay
(Tertiary)	85	M Brookian	Taglu		1.4 MM m^3			

ALASKA

YUKON & NWT

Table 2. A compilation of some of the major North Slope hydrocarbon discoveries, year, megasequence, reservoir formation, recoverable resources depths, trapping mechanisms and ancillary comments.

(data from USGS NPRA program, Petroleum Information (1980–1989), and Dixon and others, 1985)

(American Assosciation of Petroleum Geologists Bulletin, Candadian Society of Petroleum Geologists Bulletin)

ABBREVIATIONS

M = thousand (10^3), MM = million (10^6), MMM = billion (10^9).

MT = metric tonnes (1000 kg) oil

m^3 = cubic meters of gas

drill stem test information is mostly maximum per day data

multiply MMM m^3 by 3.53 E^{-2} to convert to tcf

multiply MT by 7.14 to convert to barrels

Table 3. NPRA exploration drilling results

Exploration Phase 1. 1946 - 1953

WELL	Total Depth ft	Notation
So. Barrow #1	3553	gas show
#2	2504	4100 MCFD gas L Breakup sand
#3	2900	gas show
#4	2358	1805 MCFD gas
Grandstand #1	3937	gas show at Umiat p/a
Fish Creek #1	7020	drilled at surface seeps 12 BOPD from Nanushuk sands
Oumalik #1	11872	gas shows in Torok TD in Kingak deepest well in phase 1
E. Oumalik #1	6035	weak gas show TD in Torok
Oumalik core tests (5)	178 - 392	
and permafrost tests (10)	47 - 50	
Square Lake #1	3987	112 MCFD in Torok TD in Torok
Wolf Creek #1	1500	1500 MCFD gas from Nanushuk
#2	1618	
#3	3760	730 MCFD gas from Nanushuk TD in Torok
Titaluk #1	4020	weak gas show TD in Torok
Kaolak #1	6592	TD in Torok
Knifeblade #1	1805	recovered water from Nanushuk TD in Nanushuk
#2	373	
#2a	1805	recovered water
Meade #1	5305	1132 MCFD from Nanushuk

WELL	Total Depth ft	Notation
No. Simpson #1	3774	drilled on the basis of surface seeps. 1945 - 1951 - 33 shallow "core tests" drilled in area
Simpson #1	7002	400 BOPD, 1132 MCFD gas from Nanushuk, TD in Torok
Simpson Core tests 34 wells	116 - 2505 avr. 828	6 TD in Colville Shale 25 TD in Nanushuk 3 - 125 BOPD, bailed to 350, to 4000 MCFD gas
Topagoruk #1	10503	weak gas show in Torok TD in basement
E. Topagoruk #1	3589	weak gas show in Nanushuk TD in Torok
Skull Cliffs Core Test	779	
Umiat #1	6005	oil show in Nanushuk TD in Torok
#2	6212	oil show in Nanushuk TD in Torok
#3	572	18-28 BOPD from Nanushuk
#4	840	pumped 200 BOPD
#5	1077	pumped 115-448 BOPD
#6	825	pumped 33 BOPD
#7	1834	bailed some oil
#8	1327	flowed 60 BOPD, 5859 MCFD gas
#9	1257	pumped 240 BOPD with gas cut
#10	1573	bailed 290 BOPD
#11	3303	recovered water
Gubik #1	6000	flowed 2883 MCFD gas from Nanushuk, TD in Torok
#2	4620	flowed 8000 MCFD gas from Nanushuk, some oil, well burned, TD in Torok

Barrow Development Program 1955 - 1981
#5 - #20

WELL	Total Depth ft	Notation
So. Barrow #5	2456	485MCFD gas L. Breakup
#6	2363	3000MCFD gas
#7	2180	880MCFD gas
#8	2359	938MCFD gas
#9	2429	4900 MCFD gas
#10	2240	weak gas show
#11	2171	weak gas show
#13	2249	
#14	1906	3700 MCFD gas
#15	2270	1000 MCFD gas
#16	2332	dry
#17	2382	6000 MCFD gas
#18	2125	1370 MCFD gas
#19	2300	7220 MCFD gas
#20	2356	1300 MCFD gas, oil show
Avak #1	4020	weak gas show
Iko Bay #1	2731	oil show

Exploration Phase 2 1974 - 1977

Navy Wells

WELL	Total Depth ft	Notation
So. Barrow #12	2285	weak gas show
Cape Halkett #1	9900	TD in basement
So. Harrison Bay	11290	oil & gas shows in Torok TD in Lisburne
Atigaru Pt. #1	11535	oil & gas shows in Torok and Nanushuk sands TD in basement black shale
W. Fish Creek #1	11423	drilled at surface seeps oil & gas shows TD in Lisburne/Endicott?
W.T. Foran #1	8864	porosity & stain in Breakup sands, & Sadlerochit sands minor oil & gas in Lisburne TD in basement black shale
So. Simpson #1	8795	test of possible strat trap gas shows in Torok & Kingak 75 MCFD gas in breakup sand 205 ft Sag R. ss 15% av por minor coal in Sadlerochit Lisburne eroded TD basement shale w/ qtz veins

Third phase of NPRA exploration 1977 - 1981
USGS - Husky wells

WELL	Total Depth ft	Notation
Walakpa #1	3666	385 MCFD gas in Breakup sand oil stain, 18.5% porosity TD in basement gray argillite
Walakpa #2	4360	2200 MCFD gas in Breakup sand 6 miles down dip TD in basement
W. Dease	4173	oil stain, porosity in Breakup sand TD basement argillitic shale perpendicular bedding
Tulageak #1	4015	recovered water TD basement
N. Kalikpik	7395	minor gas show & stain in Nanushuk & Torok TD Kingak shale
N. Inigok #1	10170	80 MCFD gas Breakup sands TD Shublik
Koluktak #1	5882	minor gas shows in Nanushuk TD Torok shale
Awuna #1	11200	lone test of triangle zone thrust-repeated Torok sands 2000+ BWPD fracture porosity minor oil & gas shows in Torok TD Fortress Mountain sands
So. Meade #1	9945	gas show in Nanushuk & Torok multiple Breakup sands oil show in Saddlerochit sand massive ss & cgl in Sadlerochit Lisburne eroded TD basement ss, cgl, coal & shale

WELL	Total Depth ft	Notation
Kugrua	12588	99 ft U Breakup sand 117 ft L Breakup sand 13.4% por minor gas show in Nanushuk 1195 ft Sadlerochit Gp low por TD Lisburne limestone
Kuyanak #1	6690	last well drilled TD basement
Drew Pt. #1	7946	16 ft oil stained Sag R. sand oil stain in Shublik sands oil stain in Sadlerochit sands Lisburne Gp eroded TD basement gray-black schist
Inigok #1	20102 20046 logged	minor oil show & porosity in upper Sadlerochit H2S in Lisburne, gas show coals & conglomerate Kekiktuk TD Kekiktuk
Ikipikpuk #1	15481	minor coal associated gas show in Nanushuk sands upper and lower Breakup sands 42 ft 13% por. 46 ft. 3-6% por Sadlerochit av. por 13% minor coal in Kekiktuk TD Kekiktuk/metamorphics?
E. Simpson #2	7505	minor oil & gas shows in Torok oil in Sag R. sand 20.3% por oil in Sadlerochit por. to 19% no Lisburne TD basement red clst argillite bedding near perpendicular
J. W. Dalton #1	9367	follow up to W.T. Foran #1 oil show in basal Torok oil shows in Sadlerochit sands Dst produced water, minor gas heavy oil in Lisburne DST produced heavy oil, water TD basement argillite

WELL	Total Depth ft	Notation
E. Simpson #1	7739	minor gas shows throughout L Breakup sands intbd heavy oil in Sadlerochit sands av por 11% Lisburne eroded TD basement ss & argillite steep dips
Seabee #1	15611	oil & gas shows in Nanushuk 6700 MCFD test w/depletion minor gas shows in Torok Ft Mt all units thickened by faults TD Pebble Shale
E. Teshepuk #1	10664	17 ft. Breakup sand por. 7-14% minor gas show in Pebble Shale TD granite?
Lisburne #1 (Ivotuk Hills)	17000	drilled on surface oil seeps multi-fault repeated Lisburne ubiquitous oil stains, minor gas shows TD Lisburne
Peard #1	10225	minor gas shows in Nanushuk and Torok 37 ft U. Breakup sand 128 ft intbd. L. Breakup sand minor porous sand in Sadlero- chit Lisburne eroded TD basement slst, sh, argillite bedding near vertical

Fourth phase of NPRA exploration
industry wells

WELL	total depth ft	Notation
Chevron Livehorse	12312	twinned W.T. Foran #1 similar results p/a
ARCO Brontosaurus	6660	still confidential -36 mi. SSW from Barrow
ASRC So. Barrow 2 wells		still confidential

BLM-AK-PT-91-015-3071-985